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Transit Use and the Work Commute: Analyzing the Role of Last Mile Issues

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Abstract

This paper examines the role that public transport last mile problems play in mode choice decisions of commuters, while controlling for trip, built environment, and decision maker related variables. Last-mile problems arise due to lack of adequate connectivity between transit stops and trip origin or termination points. The paper is motivated by previous literature which has pointed out that high-quality public transit needs to consider end-to-end connectivity from trip origins to destinations. In contrast to previous work on transit last mile problems which has focused on physical distance and sidewalks to transit stops, we consider a wider range of area factors including transit availability, job accessibility, parking costs, the quality of the pedestrian environment and risks to pedestrians from vehicular traffic, and social characteristics such as street-level crime. Using a discrete choice model, our goal is to unpack ways in which such factors contribute to the last mile problem in home-based work trips, while controlling for these wider range of factors as well as the usual variables such as cost and trip time that inform mode choice. We find that the prevalence of non-domestic violent crimes reduces the odds of using all types of non-motorized alternatives as well as transit that is accessed either by walking or driving. Using compensating variation to measure welfare changes, we show that there are significant benefits that could be brought to transit service users

through increasing safety in the transit access trip. By separately controlling for origin and destination transit accessibility, we show that improved destination accessibility significantly boosts transit use to a greater degree than increases in origin level accessibility. These findings argue for improving accessibility and related job densities at employment centers.

Keywords: Transit use, Last mile problems, Crime, Accessibility, Destination Accessibility, Mode choice

1. Introduction

A recurring theme in the transit planning literature is how transit could play a larger role as a transportation mode in cities and metropolitan areas. The solutions suggested range from changes to the built environment to support higher-quality transit, to altering the costs of transportation alternatives to make transit more competitive and appealing. Part of making transit appealing has to do with the transit ride itself: fare levels, service frequency, the quality of the waiting environment, and in-vehicle amenities. However, it is also important to pay attention to the built and social environments between transit stations or stops and home, work or other locations where people’s travel originate or eventually terminate. Challenges posed by built and social environment factors in the first or last leg of a trip that involves transit as the line-haul mode is often called the “last mile problem” and it can have an important impact not only on the decision to use transit for the entire trip, but also on how transit users reach their boarding locations or their final destinations after alighting from transit.

Last mile problems, particularly physical distances between stations and trip origins or destination points that are greater than what people are typically willing to walk, have been documented for a long time as a critical factor affecting transit use. While transit operators have some control over the last mile experience, mainly by altering the location of transit stations for improved proximity to origin or destination points of demand, and by improving the feel and quality of stations, the issues that affect the quality of the last-mile trip are broader. In addition to proximity, access conditions depend greatly on multiple characteristics of the built and social environment in which the last-mile trip takes place. These include physical connectivity issues such as the absence of comprehensive and connected sidewalk or bicycle lane systems, place-based barriers such as safety risks from vehicular traffic, and social and perceptual factors such as the absence of retail and employment opportunities and presence of deterring streetscapes and street level crime in transit accessways or at stations. There are a myriad of other factors including lack of dedicated last-mile solutions such as connecting transport or lack of information that can deter access to transit from trip origins or egress from transit to final destinations. The last mile problem, therefore, is a complex multidimensional problem that has physical, place-based, social and perceptual components, addressing which

would require a multi-pronged approach consisting not only of transportation and urban design solutions, but also broader social policies.

Our goal in this paper is to unpack the factors that contribute to the last mile problem in the context of mode choice, while controlling for the usual variables such as cost and trip time that inform decision making. The paper builds on our previous work to empirically understand the role that neighborhood factors play in the choice of travel mode for home-based trips. In an earlier paper (Tilahun et al., 2013), we looked at how car-owning transit users access transit boarding locations. The results showed that much of the transit access mode choice is explained by variables such as the travel time of the access mode and the characteristics of the decision maker (e.g. age, number of vehicles). We also found that increases in neighborhood-level factors such as population density and percentage of minority populations were associated with increases in the odds of walking to the boarding location relative to driving, while the availability of parking at transit stations was associated with a decrease in the odds of walking as compared to driving to the boarding location. In another paper, using a stated preference approach, we explored the variables that influence walk-transit access to stations (Tilahun and Li, 2015) and found that walk times, perceptions of crime, and sidewalk availability were important in influencing choice.

In this study, we consider a broader set of travelers (pedestrians, transit users, drivers etc) and investigate the role that different individual, household and social factors, the built environment and other place-based factors, as well as trip characteristics, influence mode choice. While travel mode choice has a long and voluminous literature, detailed characteristics of the physical and social conditions at the trip origin and destination which potentially act as last mile barriers to using specific modes have been considered to a lesser degree. Alongside more traditional variables such as travel time and out of pocket costs, we characterize the quality of the overall trip that each alternative transportation mode provides considering pedestrian safety (as measured by crash statistics), crime levels (as given by the crime statistics in the area), degree of pedestrian friendliness (as measured by a composite index), and transit accessibility (measured by a cumulative opportunities measure). The approach allows us to estimate the degree to which these attributes influence mode preferences and thereby adds to recent work that have paid increasing attention to last mile issues and have explored potential solutions (Shaheen and Finson, 2003; Brons et al., 2009; Nelson Nygaard Consulting Associates, Alta Consulting, CALSTART, and Intrago Mobility Services, 2009; Cheng et al., 2012; Wang et al., 2012).

The overall policy motivation is to understand physical and social barriers to the last mile problem and to present an approach by which different configurations of last-mile barriers may be identified, measured and addressed towards the goal of boosting transit ridership. For example, we analyze the extent to which transit access by different modes of transport are related to sociodemographic factors and how they vary between peak and off-peak hours. We also assess the extent to which varying levels of origin and destination accessibil-

ity surrounding transit facilities support various “transit access modes” such as walking, bicycling or shared rides for transit access or egress trips. The analysis allows us to identify policies and the mix of transportation solutions needed to improve last mile problems. Additionally, we analyze how potential transit users are likely to value non-transportation programs that reduce social barriers within the context of the last mile problem, with a particular focus on reducing station-area crime. This multi-pronged approach allows us to come up with a comprehensive approach to understanding the last-mile problem and the mix of solutions needed in areas with different types of last mile problems.

A key element in the analysis is the amount and types of data that we have gathered to characterize the environments in which mode choice decisions are being made. Recent years have seen much wider availability of public and private data that characterize urban environments. We take advantage of these increasingly available data sources to characterize the built environment, the social environment, as well as the performance of the different transportation systems available to users at fairly disaggregate geographies to study how these affect mode choice behavior. We use, for example, crime data available from the City of Chicago’s open data portal to evaluate the level of crime prevalence around transit stations. We exploit the potential offered by Open Street Maps and GTFS data to compute fairly detailed travel times and transit accessibility levels. We leverage parking rate information that is made available by different web portals to create a better picture of the costs travelers face for parking when destined to different parts of the metropolitan area. By combining these sources of data along with traditional sources such as those collected by planning agencies and the Census Bureau, we build a more realistic image of the urban context within which travel decision makers are making choices.

The rest of the paper is organized as follows: in Section 2, we present background information on factors explaining mode choice with a particular focus on trip-maker’s neighborhood-level factors, and on relevant work on the last-mile barriers in passenger transportation. Section 3 describes the research approach and the data used for this study. The analysis is presented in Section 4 and results are presented in Section 5. Section 6 provides a summary and discussion based on the model results.

2. Background

A voluminous literature has considered factors that affect travelers choice of mode of transportation. Factors generally considered important include: (1) mode-specific costs and level of service factors including travel time, out-of-pocket cost, waiting time or generalized cost of travel by alternative modes, parking availability and cost, service frequency, time-of-day of transit service and hours of operation; (2) household-level factors such as household size, number of children, income, availability of personal vehicles, race and ethnicity, and related factors; (3) individual traveller-level factors including gender, age, employment, schedule, need to provide child or other care services; and (4) land-use, urban design and accessibility factors, including land-use mix, availability of sidewalks

and other pedestrian factors, population and/or employment density, job or social opportunities accessibility and other related factors.

Several authors have noted that the built environment and socio-demographics are important in influencing people's mode choices ([Dieleman et al., 2002](#); [Ewing and Cervero, 2001, 2010](#); [Frank et al., 2008](#)). Using the results of over 200 studies, [Ewing and Cervero \(2001\)](#) synthesized existing literature on the built environment and travel behavior. Their synthesis suggests that both sociodemographic and built environment variables affect mode decisions. Others have also examined neighborhood environments at either origin or destinations or both in their models. For example, [Cervero \(2002\)](#) and [Rajamani et al. \(2003\)](#) assess the impact of the built environment at origin and destination on mode choices and conclude that land use pattern would encourage walking and reduce SOV commuting. [Chen and McKnight \(2007\)](#) analyzed the relationship between density and mode choice for home-based tours by considering three dimensions of the built environment: population and employment densities, job accessibilities and distance to transit stops, and concluded that built environment is significant in influencing mode choice, but that the level of influence varies at origin and destination, particularly with density at destinations being more important compared to neighborhood characteristics at origins.

Some papers also separate mode choice for different trip purposes or different commuter groups. [Cervero and Radisch \(1996\)](#) compare the influence of the built environment on mode choice for both work and non-work trips in two neighborhoods in San Francisco Bay area. They find that neighborhood characteristics are more influential on non-work trips than work trips. [Plaut \(2005\)](#) looks at factors influencing people's non-motorized mode choice including neighborhood environment characteristics. He separates homeowner and home renter commuters and emphasizes that home renters have larger flexibility of changing neighborhood locations thus alter their travel behaviors than homeowner commuters suggesting that the magnitude of the neighborhood influence on mode choice could vary among commuters.

Factors that can improve the transit experience and improve ridership can be broadly divided into internal and external factors ([Taylor and Fink, 2003](#)). Internal factors are those over which transit managers exercise some control such as fare, service quantity and service quality factors. Many strategies to improve public transit ridership focus on the actual transit service levels and use conditions. But high returns can potentially also be achieved by facilitating convenient and safe access to transit facilities. [Brons et al. \(2009\)](#) for example find that rail stations accessibility is an important aspect of whether rail is chosen as travel mode. They show that facilitating access to rail is more important than providing parking lots at the stations or improving rail travel itself.

Several authors have commented on various aspects of the transit facility access problem, including the role of the built environment and role of social factors such as crime and road safety. [Cervero et al. \(1995\)](#) note that people in denser places usually walk to transit stations in contrast to individuals in suburban settings who frequently drive. They also note that transit catchment areas are larger for lower density suburban places than higher density down-

towns. [Ker and Ginn \(2003\)](#) have also noted that the assumption of transit station walking catchment areas being 400 meters or 800 meters may be an underestimate of actual transit catchment size. Their research highlighted that people are willing to walk longer distances to reach transit stations especially rail stations. [Daniels and Mulley \(2011\)](#) also note that walking distance to transit stops is mostly related to the mode of transit being accessed and that people are more likely to walk longer distance to train stations than to bus stops. These works suggest that the experience of the environment in which transit is being accessed as well as the quality of service influence actual catchment areas around stations. [Park \(2008\)](#) also notes that street design, the quality of path walkability, and the walking distance significantly affect people's mode choice to transit stations. Land use & urban design variables may combine indifferent ways to create positive or negative experiences of safety as well as aesthetics ([Cervero and Kockelman, 1997](#); [Ewing and Cervero, 2001](#)) which may in turn influence different travel behavior decisions.

Another line of research has also focused on safety, and personal well-being while accessing transit facilities. [Kim et al. \(2007\)](#) noted that the level of crime around stations impacts transit ridership as well as the mode choice to transit stations. They noted that female riders were more likely to be dropped-off or picked-up from stations rather than walking at night from or to stations. The effect is especially higher when the stations are reputed to have higher levels of crime. Using a stated preference survey, [Tilahun and Li \(2015\)](#) also find that crime perceptions, presence of sidewalks, and access times to stations are important determinants of the decision to walk to transit stations. [Walton and Sunseri \(2010\)](#), on the other hand, found that fear of crime, distance to transit stops, carriage of goods, or concern for time are of lesser importance compared to the convenience of the car and bad weather in explaining why people drive instead of walk to transit.

Our analysis builds on these research efforts by incorporating both origin and destination level factors that may influence the choice of mode along with detailed data on transit service availability, pedestrian environment, network level variables, automobile crashes, transit station area crime, and personal constraints, in a transit rich region. By incorporating variables such as crime and crashes, we aim to incorporate not only the effects of built environments, but also of issues such as perceptions of safety that may arise from crime prevalence in an area, or roadways that may feel like they are a danger to cross on account of reported crashes in an area. Section 3 describes the data and approach used in this paper.

3. Approach and Data

Our work assumes that mode decisions are made by a rational utility maximizing decision maker. The choice of mode is assumed to depend on the relative costs and attributes of the different alternatives, household and personal factors, trip purpose, as well as built environment and social factors at the origin and destinations of a trip. Household and personal factors that may be important

include household size, income, number of vehicles, presence of children, number of adults in the household, as well as individual characteristics such as gender and age. We also assume that neighborhood level factors such as how well the home neighborhood and destination are served by transit, job and population density, walkability of the neighborhood, as well as street level safety from crime and pedestrian safety from traffic may play a role in the mode choice decision.

Identifying the role of these myriad factors required that we build a database that is able to provide details about travelers and their mode choice as well as granular data on land use, the transportation network in the metropolitan region, the quality of transit service, the pedestrian environment in different neighborhoods, the socio-demographic variables of different areas, as well as data on social phenomenon such as crime. Several different data sources were used to compile this data. The core of the behavior data which described the mode choice and purpose of the trip as well as the characteristics of the travel maker and their household comes from the 2007-2008 Travel Tracker data collected by the Chicago Metropolitan Agency for Planning (CMAP) from eight counties in the North-Eastern Illinois area ([NuStats, 2008](#)). This data provided origin and destination information for the trips used in this study at the census tract level to preserve anonymity of respondents. Further data linkages thus were made at the census tract level. Data that was linked to this data was: neighborhood socio-demographic data, job and population density data, crime data, pedestrian crash data, transit station locations, and data that measured the level of transit service and walkability of the neighborhood. Since the travel tracker data was collected in 2007 & 2008, all data linkages were made to available data that closely matched these years. The sources for each are discussed below.

Socio-demographic data came from the American Community Survey's 2005-2009 5-year estimates. Crime data for 2007 was taken from the City of Chicago's open data portal, which provided details about location as well as nature of crime. Data on the locations of transit station data was also gathered from the City's data portal. The total number of jobs in each census tract was gathered from the Census Bureau's Longitudinal Employment-Household Dynamics (LEHD) Work Area Characteristics (WAC) file for 2009.

Travel times for the mode used by the respondent is available in the Travel Tracker data. Over 75% of the observations in the data have arrival times at the destination between 6:00-10:00 AM. For the alternative modes, tract to tract travel times were calculated using a mass-request tool which queries Microsoft's Bing maps assuming departures taking places at 7:30 am. These travel times are then adjusted using the ratio of Bing reported travel time to the reported travel time for the mode the respondent used. For example, if the auto travel time reported by commuter exceeds the Bing estimate by 10%, then travel times for the alternatives are also raised by 10%. Since actual travel times for the reported mode use the true OD of the trip, this seeks to make the Bing estimates, which are centroid to centroid, more in line with the true OD trip.

Parking data was collected from various Internet sites and using parking rates provided by transit providers. This data was used to generate an interpolated parking raster data for the Chicago area which was then used to get

Table 1: Data sources and years used in study

Data type	Source	Year
Travel Behavior Data	CMAP Travel Tracker	2007-2008
Socio-demographic data	U.S. Census (ACS)	2005-2009
Jobs Data	U.S. Census (LEHD)	2009
Crime Data	City of Chicago	2007
Transit Availability Index	Chicago SDSS	2005
Pedestrian Environment Factor	Chicago SDSS	2000
Pedestrian Environment Index	Peiravian et al. (2014)	2013
Accessibility	Tilahun et al. (2015)	2011
Parking Data	Phone Calls, web search	2013

parking costs for modes that included driving as an option. Cumulative opportunity auto and transit accessibility data for the metro region was computed using the Open Street Maps network and the LEHD’s Work Area Characteristics (WAC) data ([Tilahun et al., 2015](#)). These accessibilities are computed at the census block group level and aggregated to the tract level by taking an average. The accessibility values used here correspond to the 8am departure time for each census tract.

A Chicago-area data resource, the Spatial Decision Support System (SDSS) ([Thakuriah, 2008](#)), was used to characterize transit service and pedestrian environments around the reported mode choice locations. The SDSS provided a transit availability factor (TAI) ([Minocha et al., 2008](#)) and a pedestrian environment factor (PEF) ([Cottrill and Thakuriah, 2010](#)). The TAI computes a composite measure of transit availability by combining frequency, hours of service, and service coverage for the regions Bus and Rail systems. The PEF is the average number of blocks for the quarter section within each census tract and the eight adjacent quarter sections computed using the 2000 census block geographies. A higher number of blocks suggests more local streets and a regular street network ([CMAP, 2012](#)). In addition, a pedestrian environment index (PEI) was also included in the data using the work of [Peiravian et al. \(2014\)](#). The PEI is a composite index that combines land use diversity, population density, commercial density, and intersection density.

Table 1 shows sources and the years for these data. The variables that are further from the date of collection of the behavioral data are the Accessibility, Parking, and Pedestrian Environment Index (PEI) data. As variables that are closely tied to the built environment in the city of Chicago, we anticipate these to change only moderately in most areas over the period of study. While transit system modifications do occur from time to time, much of the rail system remains the same as the time of the study and changes to particular bus lines are not likely to impact cumulative opportunities accessibility measures only mildly. Table 2 provides a summary of the variables considered in this study.

As noted earlier, all trips considered in this paper are home-based trips

that originated from the city of Chicago and ended either within the city of Chicago or in the surrounding suburbs (including suburban Cook County and the collar counties in Northeastern Illinois). We use only Chicago as the origin location because the crime data is only available as point observations within the city limits only. In addition, as one moves out of the City’s limits, census tract areas get larger and makes it harder to justify the use of census tracts as representative of the origin neighborhood. The city of Chicago is divided into 801 census tracts. Average tract area is $0.3mi^2$, whereas the average census tracts for the metropolitan area excluding Chicago has an area of $4.9mi^2$. In the analysis, we only use trips that are reported as work, work-related, school, and school-related because the mode choice decisions for these trips is likely to be stable and repeating for each respondent. The Travel Tracker data was gathered over one day for some respondents and over two days for others. As a result, it was possible for the same person to appear several times in the data. For those who have multiple observations, we randomly select one observation to be included in the analysis.

Chicago has an extensive bus system and a well-established transit network of commuter trains and rapid transit lines that has had two major additions in the last 20 years: the Orange Line to Midway Airport, which opened in 1993, and the North Central Line, commuter railroad service to Antioch, IL, which opened in 1996. Table 3 shows the mode shares of the trips considered in this study from the City of Chicago to within the city and outside of the city. The dominant mode is auto, with solo driving being the preferred mode particularly to suburban destinations, and carpooling a less used form of car-based transportation. There is substantial transit use when trips are destined to the city of Chicago accounting for 37.3% of the Chicago-destined trips used in the analysis. By far the dominant mode of access to transit is walking. Overall the average trip has a straight line distance of 6.7 miles, though trips destined outside of Chicago averaged 13.1 miles while those ending in Chicago were on average 5 miles. About 80% of the trips used in this analysis started and ended in the City of Chicago while the remainder ended in nearby suburbs.

4. Analysis

Our analysis assumes a utility maximizing rational decision maker. We specify the indirect utility function (V) for the person k going from location i to j by mode m as follows (we drop subscripts i and j for clarity below):

$$V_m = \beta_m + \beta_1 T_m + \beta_2 \frac{P_m}{I_k} + \beta_3 C_m + \theta' X_k + \gamma' O_k + \eta' D_k + \zeta' R_k$$

where:

T_m : Travel time for mode m ;

P_m : The out of pocket cost for mode m ;

I_k : Household income for respondent k (expressed as annual income (1,000s)).

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Table 2: Summary of variables used in the study

Variable name	Sample mean	Included in final model?
Person & household level variables		
Gender (1= Male)	0.486	Y
Age	43.2	Y
Vehicles/household size	0.646	Y
Household size	2.47	Y
No household vehicles	13.2%	Y
Income	\$76,693	Y
Trip variables		
OD Travel time (minutes):		
Auto	19.9	Y
Transit (walk accessed)	44.4	Y
Transit (auto accessed)	54.5	Y
Bicycle	35.1	Y
Walk	25.5	Y
Out of pocket costs:		
Auto (operating costs+ parking)	\$8.10	Y
Walk accessed transit (fare)	\$2.35	Y
Auto accessed transit (parking+fare)	\$3.23	Y
Area Transportation Variables		
Origin transit accessibility (30 min)	3.3%	Y
Destination transit accessibility (30 min)	8.1%	Y
Transit availability index (TAI) (composite index)	0.716	N
Road length (<i>mile</i>)/tract area (<i>mile</i> ²)	0.018	N
Road length in tract (<i>mile</i>)	2.65	N
Pedestrian environment factor (PEF) (block density)	16.8	N
Pedestrian environment index (PEI) (composite index)	0.403	N
Neighborhood-Level Variables		
Population density at origin (<i>people/mi</i> ²)	18467	N
Population density at destination (<i>people/mi</i> ²)	14491	N
Job density at origin (<i>jobs//mi</i> ²)	6738.7	N
Job density at destination (<i>jobs//mi</i> ²)	61064	Y
Violence in 1/2 mile and 1 mile of station (origin)	249 & 874	Y
Percentage of non-white pop. (origin)	47.9%	N
Percentage of black pop. (origin)	29.3%	Y
Median household income at origin	\$50,885	N
Distance to downtown (origin)	6.92 <i>miles</i>	N

Table 3: Mode shares and average travel times of trips used in model development

	All	Suburban destination	Chicago destination	Average distance (<i>mi.</i>)
Mode shares				
Drive alone	50.4%	78.2%	43.4%	7.9
Shared ride	7.2%	7.3%	7.1%	6.2
Transit (Auto access)	3.6%	1.0%	4.3%	8.8
Transit (Walk access)	29.5%	11.4%	34.0%	5.8
Walk	6.1%	1.3%	7.3%	1.4
Bicycle	3.2%	0.8%	3.8%	3.2
Summary stats				
Average				
Distance (<i>mi.</i>)	6.7	13.1	5.03	
% trips	100%	20%	80%	
Total trips		1948		

C_m : A measure of level of crime a person would be exposed to by choosing mode m in the vicinity of the origin. We use the number of non-domestic violent crimes that happened in 2007 within half a mile of boarding (for auto accessed transit) or within one mile of origin (for walk, bike, walk-transit modes). The variable takes value 0 for SOV or HOV modes. The SOV and HOV modes are assumed to shelter one from violence. The remaining modes either expose the decision maker to crime in the vicinity of the boarding location or in the path they take. Expressed in 100s.

X_k : A vector of socio-demographic variable associated with the respondent k (such as age, gender, their household size, household vehicles etc.)

O_i : A vector of neighborhood variables associated with the origin of the trip (transit accessibility, households with no vehicles, etc.)

D_j : A vector of neighborhood variables associated with the destination of the trip (such as population density, transit accessibility, etc.)

R_k : A vector of trip related variables for person k (such as purpose, arrival time at destination, etc.)

$\theta, \gamma, \eta, \zeta$: Parameters to be estimated for each mode m

β : Parameters to be estimated for the alternative varying variables of travel time, out-of-pocket cost, and violent crime

The analysis here is applied to home based work, work related, school and school related trips reported by residents of Chicago. The choice of analyzing the city separately was mainly driven by granular level data, particularly that of crime around transit stations, which may deter those wanting to access stations

by non-motorized modes. A multinomial logit model is used to analyze the effect of these attributes on respondents mode choice. The model uses three alternative specific variables —travel time costs, out of pocket costs normalized by household income, and the potential for the traveller to encounter violent crime as a result of using a particular mode. We assume that counts of violent crimes would be closely tied to the perceptions of safety. If a person drives or carpools to their destination, we assume these alternatives avoid the potential to encounter crime. If they use an automobile to access the transit station, then we use a half-mile buffer around the likely boarding station to represent the potential to encounter crime. In cases where the person walks to a station or walks or bikes to their destination, we use the count of all non-domestic violent crimes in a one-mile radius from their origin as a measure of the perception of how unsafe that alternative mode may be.

Out of pocket costs are composed of the operating cost for a vehicle (fuel and wear and tear), fare costs, and parking costs. Not all costs apply to every mode and this variable enters the model as an alternative specific variable. Daily parking costs were calculated based on estimates developed from local parking data. The parking data, which included 321 daily parking and monthly rates at different parking facilities throughout the Chicago metro, was gathered primarily through online searches coupled with phone calls to different parking facilities. This was first used to develop a raster data through empirical kriging and linked to the origin & destination coordinates reported from the Travel Tracker data. Parking estimates were read from the raster data for both the boarding location as well as the final destination area depending on the mode a person would choose. The out of pocket cost, which reflects the fare, vehicle operating costs, and parking, enters the utility function after being divided by the household income of the respondent to account for the different marginal utility of money of different income earners.

Individual and household level factors are also assumed to affect the choice of a mode. We incorporate gender, age, household size, presence of household vehicles, and the number of vehicles available per household member 16 years or older, to capture how these variables affect mode choice. A variety of origin and destination level factors are also incorporated into the model to estimate their effect on mode choice. On both the origin and destination ends, we incorporate population density, job density, cumulative 30 minute transit job accessibility (expressed as a percentage of regional jobs), and pedestrian environment measures to capture local area variables. At the origin end, count of non-domestic violent crimes as well as socio-demographic characteristics of the origin including median income and racial composition are tested in the model.

The model was estimated using the mlogit library in R ([Croissant, 2012](#)). A number of variables that were collected for the data effort were dropped from the final model either because they were not significant in explaining mode choice (e.g. count of automobile crashes at origins) or because they were highly correlated with variables that were eventually included in the model (e.g. pedestrian environment factor with origin level transit accessibility; destination job density with destination level transit accessibility). Where correlation was an issue, we

opted to keep the variables that were explanatory and were policy sensitive. The base category for the model is the drive-alone mode and the final model is reported in Table 4.

5. Results

The findings of the model are discussed below separated by the type of variable. Where income is involved we use the 2013 median household income as estimated by the 5-year American Community Survey which shows a median income of \$47,270 to discuss values extracted from the model.

Mode-specific variables: The model has three alternative specific variables —travel time, price (which enters as price/income), and crime exposure. The model clearly suggests that travel time costs as well as out of pocket costs are important considerations in the choice of a mode. The model estimates a willingness to pay of \$28.08/hour for someone whose household income at city’s median income (\$11.88/hour and \$59.40/hour for incomes of \$20K and \$100K, respectively).

Neighborhood level crime that one may encounter is another factor that comes out as important in mode choice decisions. As discussed earlier, in the specification of the model this variable takes on crime count values for the transit alternatives (being dropped off or walking to transit), bicycling and walking. Automobiles are assumed to limit exposure to street crime. The estimates suggest that as neighborhood crime increases, the probability that travelers would choose an automobile alternative for their trip increases, all other things equal. For example, if there were to be an additional 100 non-domestic violent crimes annually in an area, the odds of choosing the non-automobile modes decreases by about 5%. The model suggests a willingness to pay of \$0.86 per hundred non-domestic violent crimes in the vicinity of transit stations for someone making the median income. This is about 43% of the \$2.00 current bus fares in the Chicago area.

Using the model, we estimate the value residents associate with violent crime reduction in their neighborhood by calculating compensating variation (CV) estimates. The CV estimates how much money one can compensate (or take away) from a decision maker after a policy change to return them to the utility level they had before the change. The value is used to monetize the impact of the policy. [Small and Rosen \(1981\)](#) have shown that this can be calculated by taking difference in the *logsum* at two policy points and multiplying it by the reciprocal of the marginal utility of income: ($CV = \frac{-1}{\lambda} [\ln \sum_k e^{V_k}]_{v_1}^{v_2}$). The marginal utility of income (λ) in our case is equal to β_2/I_k . The approach has been used, for example, to value mode-destination accessibility ([Niemeier, 1997](#)).

To demonstrate the economic value of successful crime prevention policies or programs, we estimate the compensating variation for a 10% decline in violent crimes that may be achieved through such a program. We estimate the CV using a representative decision maker in each census tract that has their characteristics derived from the 2013 ACS. The decision maker is a female traveller, having the

median income and age of the tract. Her household size, number of children and adults, as well as the number of vehicles in the household reflects average household characteristics for the tract. The 10% reduction for each census tract is applied to the 2007 crime levels around each tract's centroid. This means the crime reductions for high-crime areas in absolute numbers are larger than for low-crime areas. Travel time and out of pocket costs are set at the average levels in the model. Since the model includes destination accessibility as an important factor in mode choice, we compute separate CV estimates for low cumulative accessibility destinations (set at 0.5% of regional jobs) and high accessibility destinations (set at 30% of regional jobs). Figures 1a and 1b show the compensating variation values for each origin tract when trips are destined to low accessibility and high accessibility destinations respectively. Figures 1c and 1d show the prevailing crime levels using the 2007 crime data for each census tract. The high crime areas to the west and south of the city in Figures 1c and 1d are also amongst poorer parts of the city while the northern part of the city is higher income.

As Figure 1 shows, a 10% reduction in crime at the origin end can be valued up to \$2.74 depending on the characteristics of the origin and the destination. As the figure shows, reductions are particularly valued in places where existing crime levels are high. In addition, much of the northern parts of Chicago, where incomes tend to be higher, also have higher estimates for the compensating variation. Current bus fares for Chicago Transit Authority are \$2.00 per trip. The compensating variation values suggest that the benefits of a 10% reduction in violent crime is such that, if it were to be achieved, fares could as much as double in some areas and the respondent's utility would not be affected. When destination accessibility is high, in many parts of the city, price increases of 25% (\$0.50) would be tolerated without a loss in utility in many parts of the city. It is also interesting to note that CV values that are greater than \$1.00 are observed in figure 1 in both the poorer sections of the city (west and south) as well as in the central business district and northern parts of the city. When the destination accessibility is not as high, however, almost all decision makers have compensating variation values that are below \$0.50. This is in part because the non-auto mode utilities to low accessibility destinations are already small and a reduction in crime in these cases does not alter the utilities of the decision makers substantially. Overall, this analysis suggests that there are significant benefits to be derived for transit usage by addressing safety concerns at the origin end, making transit a more desirable alternative.

Individual & Household Variables: Gender, age, vehicle availability, and household size play important roles in mode choice for the trips we are considering. Men prefer bicycling compared to women ($p = 0.019$), all things equal. Though the model suggests that men tend to use shared rides (HOV use) less than women, the p-value is large ($p = .107$) and no significant effect is discerned. For the trips considered here, both bicycling and walk-accessed transit are negatively related to age relative to the drive-alone mode ($p < 0.001$ in both cases). Each additional year of age reduces the odds of walking to transit by 1.8% and the odds of bicycling by 4.4% respectively. Not unexpectedly,

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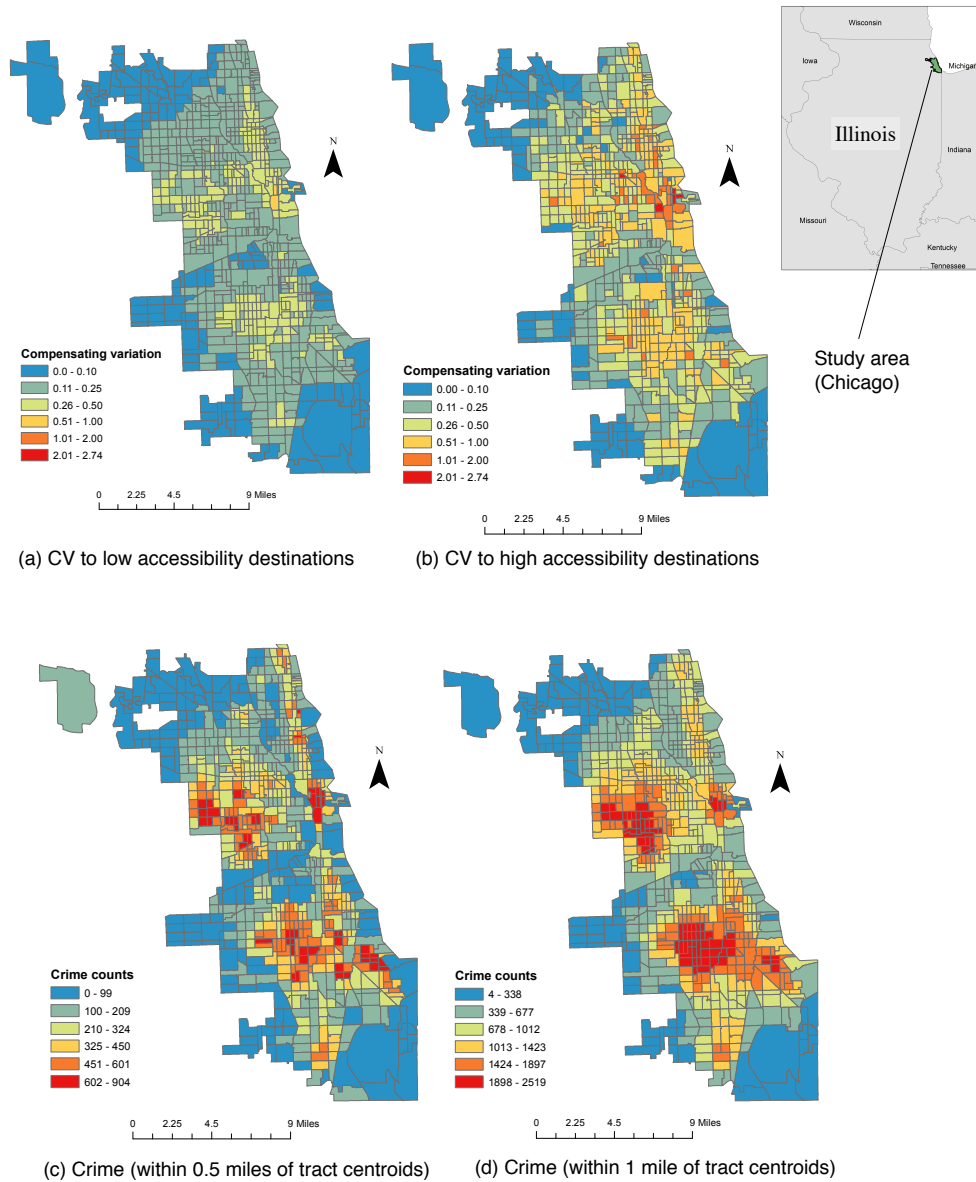


Figure 1: Compensating variation (CV) for different census tracts for a 10% reduction in crime (a & b) and crime counts at tract centroids (c & d). The compensating variation shows the value of the 10% reduction in $\$15$ terms by asking “how much income can a representative resident in a tract give up and still remain at the same utility as before the crime reduction?”

households with no vehicles were significantly more likely to choose one of the alternatives to the automobile, with walk-accessed-transit having the highest odds of being chosen over all other options, other things equal. In households with vehicles, higher vehicles per household adult (16 years or over) indicates a preference for choosing the automobile over all other modes except the choice of the auto-accessed transit option; an increase in vehicles per adult does not alter the odds of use of the automobile for the entire trip over the auto-transit option. Respondents from larger households were also less likely to walk ($p = 0.019$), less likely to use walk-accessed transit ($p = 0.096$), and more likely to use shared rides ($p = 0.019$).

Place variables: As described in the mode-specific variables section above, crime at the neighborhood level deters use of those modes where one would be exposed to street level crime (walking, biking, accessing and waiting at transit station area). In addition, we find the proportion of households with no vehicles in the respondent's tract to be important descriptors of choice. In particular, respondents with higher numbers of zero-vehicle households in their residential tract were more likely to use the walk-accessed transit mode or the walking mode to destination all things equal. This is after controlling for whether the respondent has no vehicles, the number of vehicles per household adult, and the level of transit service in the origin tract as measured by origin level transit accessibility. It is possible that people who live in places where a larger number of others walk to their destinations or access transit by walking also adopt these alternatives.

Transit accessibility levels at the origin and destination were also found to be important in influencing mode choice. We use a cumulative opportunities measure for accessibility measurement. This measure simply counts how many jobs can be accessed in the metropolitan area from a given origin within a 30 minute travel time by transit. The logarithm of the accessibility measure is used in the mode choice model (both at origin and destination). The use of a log transform implies that equivalent changes in accessibility at a place with very small accessibility and very high accessibility will have different impacts on a persons utility (i.e. an equivalent change in absolute numbers would have higher impacts on utility for places with lower accessibility). This aligns with our intuition. The addition of a transit line in a downtown that is already well served by transit is less likely to lead to a large mode shift, whereas a new line that opens up access to a place with limited or no transit may bring about a substantial mode shifts.

We find that a one unit shift in origin accessibility makes it more likely to bike ($p = .007$) and walk ($p = 0.081$), and less likely to use auto-accessed transit. Surprisingly, there was no impact of origin accessibility on making walk-transit a more preferred option. Destination accessibility (measured the same way), on the other hand, made every other option except walking more likely to be chosen relative to the auto mode, other things equal. For every unity increase in destination accessibility (log scale), the odds of using an HOV rose by 21% ($p < 0.001$); that for biking rose by 39% ($p\text{-val}=0.003$) and that for walk-accessed and auto-accessed transit rose by 63% ($p\text{-val} < 0.001$) and

149% ($p - val < 0.001$) respectively.

It is possible that there are several reasons for the positive association between destination accessibility and transit use. One reason may be that places with higher accessibility often have good transit service through out the day. This makes it easy to accommodate changes in schedule and to have mobility options if/when needed, which is often desirable. In addition, accessibility may be capturing attributes of places that go beyond the the travel time and reachable jobs components of the measure. High accessibility is closely related to higher job density, higher population density, and to better pedestrian environments.

Figure 2 shows how destination accessibility in the data is related to these density and walkability related variables. The pedestrian environment (PEI) in the figure includes components of population and commercial density, land use diversity, and intersection density as described earlier in Section 3. These high degrees of correlation suggest that some of the attractiveness of high accessibility destinations is possibly due to the strength of diversity, density, and potentially design features. Not all these variables could be included in the model either because they were not available for all destinations (as in the case of the PEI) or were correlated with an existing variable (as was the case of job density) or were unimportant in explaining choice (as was the case for destination population density).

Trip related variables: Two trip level variables are included in the model. The first identifies whether the arrival hour at the destination is between 6-9am, and the second identifies work trips separate from the remaining trips (work related, school, and school related). Work trips and trips whose arrival at their destination is between 6-9am increase the odds of using transit (walk accessed as well as auto accessed) relative to non-work and out-side-of-peak-hour trips. Bicycling is also moderately more likely when the trip is a work trip than work-related, school, or school-related trips ($p - val = 0.069$).

6. Summary

This paper analyzed the role of personal, built environment and modal variables on the mode choice of travelers for their work commute, with a particular focus on the transit last-mile trip. We examined factors contributing to transit first/last-mile problems. Last mile issues are often cited as one of the barriers to transit use. Often, these discussions focus on the length of access time between a person’s start point and the location of their boarding or alighting station. We have built on such studies by evaluating neighborhood-level factors and mode characteristics, while also controlling for trip and person related factors. We brought together different datasets to create a rich description of the built environment including transit availability and job accessibility measures, the pedestrian environment and risks to pedestrians from vehicular traffic, parking costs and availability, and social characteristics such as street-level safety. We find a variety of factors affect mode choice, including out-of-pocket costs and travel time, crime, levels of transit accessibility, neighborhood-level vehi-

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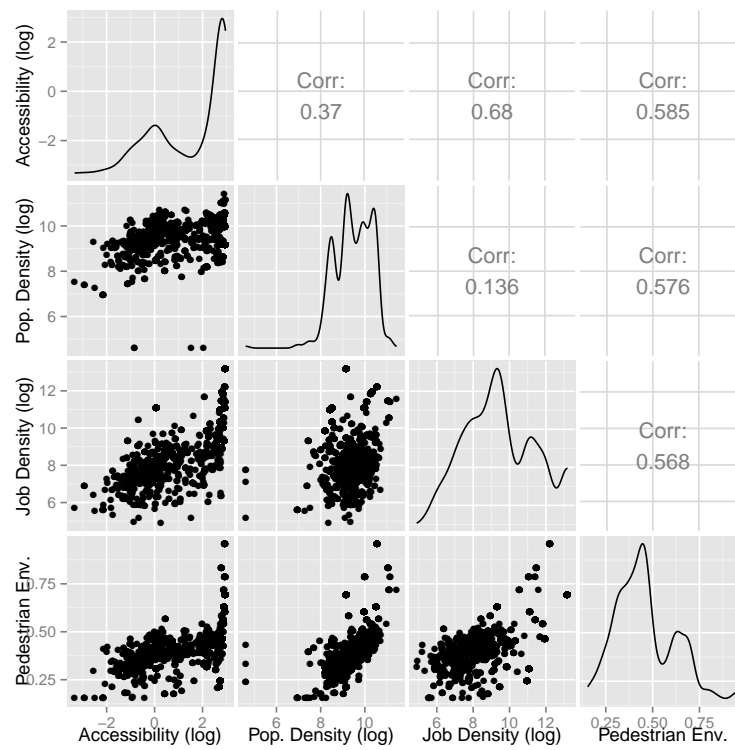


Figure 2: Correlation between destination level measures of accessibility, population density, job density, and the pedestrian environment index

cle ownership, and variables that are specific to the decision maker and their household.

We find that the prevalence of non-domestic violent crime reduces the odds of using non-motorized alternatives as well as the use of transit that involves walking or driving last-mile options to access a station. While the sign and strength of significance of observed crime levels is apparent, how well these levels correspond to people’s knowledge and perceptions of crime on the basis of which they make mode choice is less known. We are able to estimate from the model that efforts to reduce crime or improve perceptions of safety will have positive payoffs to transit use as well as to walking and bicycling; for example, the benefits of a 10% reduction in violent crimes is such that, if it were to be achieved, fares could as much as double in certain areas and yet travelers would not be worse off. This effect is heterogeneously distributed in different areas but we also note that relatively high compensating variation values are observed in both high income and low income areas of the city. Successful crime prevention programs could therefore be supported through some increases in fares without making travelers worse off, leading to improvements in service quality and potential increases in transit ridership.

A result that was robust to different specifications of the indirect utility was the impact of origin and destination accessibilities. The model suggests that those living in high transit accessibility areas were no more likely to use the walk-transit alternative as compared to the auto mode all other things equal. They were however less likely to use the auto-accessed transit option than driving alone. Rather, it was transit accessibility at destinations that seemed to strongly influence choice to use transit as compared to driving as well as to bicycle. All other things equal, those traveling to areas with high levels of transit accessibility were also more likely to use shared rides. It is important to note that the attractiveness of destination accessibility for transit is after controlling for cost differences between auto and transit, including parking costs, which are captured by the price variable. As we discuss in Section 5, the positive association with destination accessibility may in part be due to the features of job density, diversity and walkability that go along with high transit accessibility places. The finding does highlight that these features are much more important to transit takers on the destination end than they are at the origin end of these trips.

Different studies have shown accessibility (measured as cumulative opportunities, gravity based accessibility, or distance to downtown) to be an important variable in travel behavior (see [Ewing and Cervero \(2001, 2010\)](#) for a synthesis). We also find it to be important but with varying degrees of importance at the origin end and at the destination end of a trip for different modes. For bicycling, for example, both origin level and destination level accessibilities have similar positive impacts. For walking, origin level accessibilities are important. For transit use, however, it appears much more important that the destination that one is traveling to has higher accessibility. The city dweller residing in a high accessibility location may indeed drive if heading to a low accessibility destination while a suburbanite heading to a high accessibility destination may

find transit to be an attractive choice.

From a last mile research perspective these findings suggest that improvements to accessibility and associated built environment features such as job density and diversity at the terminating end of the trip maybe much more important in influencing choice. We also note that the impact of equivalent gains in cumulative accessibility is larger in areas that currently have low levels of accessibility as compared to areas that already have high levels of accessibility. Together these findings suggest that there are positive payoffs to increasing densities of employment and improving accessibilities particularly at low density employment centers.

Different socio-demographic variables were also important in informing choice. Age deterred bicycling to work. Women were less likely to bicycle. Household variables such as household size made ride sharing more likely and walking less likely. Vehicle unavailability influenced the use of non-SOV modes, while increases in per-capita vehicles in a household favors driving alone or auto accessed transit. Socio-demographic variables of the origin neighborhood as measured by the percent of households with no vehicles positively influenced the use of walk-transit or walk even after controlling for the person's vehicle ownership.

Alternative specific cost and travel time also have the expected influence on choice with higher cost alternatives and higher travel time alternatives being shunned by decision makers. Each additional minute of travel (whether to access a station or on board a vehicle) reduces the odds of that alternative. All things equal, this means alternatives that have less circuitous routes would be preferred for last mile connections.

All in all we find that safe walking environments and station areas on the origin end and high accessibility features at destinations are key elements of the transit trip and the last mile problem. These results have implications for the types of last-mile solutions needed in different areas to boost transit use. The results indicate considerable benefits to coupling transit planning activity with crime reduction and safety programs in origins of home-based work trips, but some of these strategies could potentially be organic and citizen-generated, for example, involving the use of information technology-based solutions that leverage mobile technologies to find, in real-time, walking or traveling buddies from bus stops and train stations in unsafe areas. The use of social media can be a key factor in driving these types of self-organizing, collaborative transportation connectivity options.

Finally, given the multidimensional nature of the last-mile problem, it may be useful to consider Behavior-Driven Development (BDD) or similar digital service development approaches in transit planning, where explicit "user journeys" are considered to serve transit customers with specific profiles or desired "user stories" entering and exiting the travel system in specific ways. While needs assessments and gap analysis are central in transit planning, they are typically done from the perspective of system connectivity compared to individual user connectivity. The seamless provision of user journeys will require collaboration among a large number of stakeholders and will involve connecting various physical and digital elements in the system. Such customization is typ-

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ically used in software design and web services design but if transit is thought of as a service, then such principles may very well be needed to address the vast combinations of factors that affect any one traveler's unique last-mile situation and choices. Realizing such an outcome will require the exploration of models of institutional collaboration and coordination among public, private, non-profit, community groups and others, towards the goal of addressing myriad problems that arise due to the last-mile problem.

Acknowledgement

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Table 4: Multinomial logit model for mode choice. The reference category is drive alone.

	Shared ride		Transit (auto accessed)		Transit (walk accessed)		Bicycle		Walk	
	Est.	t-stat	Est.	t-stat	Est.	t-stat	Est.	t-stat	Est.	t-stat
Intercept	-0.122	-0.194	-5.314	-4.625 ***	0.848	1.742 .	-0.182	-0.176	1.467	1.861 .
Sex (1=Male)	-0.313	-1.613	-0.272	-0.983	0.094	0.678	0.691	2.354 *	-0.089	-0.392
Age	-0.006	-0.798	-0.003	-0.261	-0.018	-3.347 ***	-0.045	-3.708 ***	-0.007	-0.913
Zero veh. HH. (1=Y)	2.546	3.648 ***	2.600	2.57 *	3.741	5.808 ***	3.129	3.784 ***	2.648	3.513 ***
Veh. per adult	-2.206	-5.721 ***	-0.557	-1.47	-2.084	-7.987 ***	-2.235	-3.565 ***	-2.457	-4.864 ***
HH size	0.184	2.354 *	-0.005	-0.038	-0.106	-1.66 .	-0.172	-1.227	-0.274	-2.351 *
Origin Access. (<i>log</i>)	-0.002	-0.026	-0.735	-5.417 ***	-0.104	-1.636	0.355	2.696 **	0.234	1.745 .
Dest. Access. (<i>log</i>)	0.191	3.343 ***	0.913	6.535 ***	0.492	9.612 ***	0.331	2.96 **	0.060	0.513
Peak-period (1=Y)	-0.200	-1.025	1.010	3.162 **	0.497	3.468 ***	0.403	1.398	0.166	0.713
Work trip (1=Y)	-0.237	-1.018	1.882	2.535 *	0.594	2.972 **	0.770	1.815 .	0.077	0.273
% 0 veh. HH Tract	-0.999	-1.241	-0.310	-0.262	1.514	2.481 *	-0.463	-0.387	2.642	2.906 **
Price (P/I)					-2.836	-7.641 ***				
Travel time (T)					-0.028	-10.191 ***				
Violent crime (V_c)					-0.052	-3.447 ***				
Goodness of fit:			Log-Likelihood: -1780.8							
			McFadden R^2 : 0.293							
			N: 1948							
			Likelihood ratio test : $\chi^2 = 1476.3$ ($p.value = < 2.22e - 16$)							

Significance: *** < 0.001, ** < 0.01, * < 0.05, .0.10

References

- Brons, M., Givoni, M., Rietveld, P., 2009. Access to railway stations and its potential in increasing rail use. *Transportation Research Part A: Policy and Practice* 43, 136–149.
- Cervero, R., 2002. Built environments and mode choice: toward a normative framework. *Transportation Research Part D: Transport and Environment* 7, 265–284.
- Cervero, R., Kockelman, K., 1997. Travel demand and the 3ds: density, diversity, and design. *Transportation Research Part D: Transport and Environment* 2, 199–219.
- Cervero, R., Radisch, C., 1996. Travel choices in pedestrian versus automobile oriented neighborhoods. *Transport Policy* 3, 127–141.
- Cervero, R., Round, A., Goldman, T., Wu, K.L., 1995. Rail access modes and catchment areas for the bart system, pp. 1–55.
- Chen, C., McKnight, C.E., 2007. Does the built environment make a difference? additional evidence from the daily activity and travel behavior of homemakers living in new york city and suburbs. *Journal of Transport Geography* 15, 380–395.
- Cheng, S.F., Nguyen, D.T., Lau, H.C., 2012. A mechanism for organizing last-mile service using non-dedicated fleet, in: *Web Intelligence and Intelligent Agent Technology (WI-IAT)*, 2012 IEEE/WIC/ACM International Conferences on, IEEE. pp. 85–89.
- CMAP, 2012. Congestion Management Process Documentation. Congestion Management Program, Chicago Metropolitan Agency for Planning. Chicago, IL.
- Cottrill, C.D., Thakuriah, P.V., 2010. Evaluating pedestrian crashes in areas with high low-income or minority populations. *Accident Analysis & Prevention* 42, 1718–1728.
- Croissant, Y., 2012. Estimation of multinomial logit models in R: The mlogit Packages.
- Daniels, R., Mulley, C., 2011. Explaining walking distance to public transport: the dominance of public transport supply. *World* 28, 30.
- Dieleman, F.M., Dijst, M., Burghouwt, G., 2002. Urban form and travel behaviour: micro-level household attributes and residential context. *Urban Studies* 39, 507–527.
- Ewing, R., Cervero, R., 2001. Travel and the built environment: a synthesis. *Transportation Research Record: Journal of the Transportation Research Board* 1780, 87–114.

- Ewing, R., Cervero, R., 2010. Travel and the built environment: a meta-analysis. *Journal of the American Planning Association* 76, 265–294.
- Frank, L., Bradley, M., Kavage, S., Chapman, J., Lawton, T.K., 2008. Urban form, travel time, and cost relationships with tour complexity and mode choice. *Transportation* 35, 37–54.
- Ker, I., Ginn, S., 2003. Myths and realities in walkable catchments: the case of walking and transit. *Road and transport research* 12, 69–80.
- Kim, S., Ulfarsson, G.F., Todd Hennessy, J., 2007. Analysis of light rail rider travel behavior: impacts of individual, built environment, and crime characteristics on transit access. *Transportation Research Part A: Policy and Practice* 41, 511–522.
- Minocha, I., Sriraj, P., Metaxatos, P., Thakuriah, P.V., 2008. Analysis of transit quality of service and employment accessibility for the greater chicago, illinois, region. *Transportation Research Record: Journal of the Transportation Research Board* 2042, 20–29.
- Nelson Nygaard Consulting Associates, Alta Consulting, CALSTART, and Intragro Mobility Services, 2009. Maximizing Mobility in Los Angeles-First and Last Mile Strategies. Technical Report 1-143. Southern California Association of Governments. URL: <http://www.scag.ca.gov/nonmotorized/pdfs/LA-Maximizing-Mobility-Final-Vol1.pdf>.
- Niemeier, D.A., 1997. Accessibility: an evaluation using consumer welfare. *Transportation* 24, 377–396.
- NuStats, G., 2008. Chicago regional household travel inventory draft gps final report. Prepared by Chicago Metropolitan Agency for Planning.
- Park, S., 2008. Defining, measuring, and evaluating path walkability, and testing its impacts on transit users' mode choice and walking distance to the station. ProQuest.
- Peiravian, F., Derrible, S., Ijaz, F., 2014. Development and application of the pedestrian environment index (PEI). *Journal of Transport Geography* 39, 73–84.
- Plaut, P.O., 2005. Non-motorized commuting in the us. *Transportation Research Part D: Transport and Environment* 10, 347–356.
- Rajamani, J., Bhat, C.R., Handy, S., Knaap, G., Song, Y., 2003. Assessing impact of urban form measures on nonwork trip mode choice after controlling for demographic and level-of-service effects. *Transportation Research Record: Journal of the Transportation Research Board* 1831, 158–165.
- Shaheen, S.A., Finson, R., 2003. Bridging the last mile: a study of the behavioral, institutional, and economic potential of the segway human transporter. Technical Report. Transportation Research Board.

- Small, K.A., Rosen, H.S., 1981. Applied welfare economics with discrete choice models. *Econometrica* 49, pp. 105–130. URL: <http://www.jstor.org/stable/1911129>.
- Taylor, B.D., Fink, C.N., 2003. The factors influencing transit ridership: A review and analysis of the ridership literature. University of California Transportation Center .
- Thakuriah, P., S.P.M.P.M.I.T.S., 2008. Economic and social urban indicators: A spatial decision support system for chicago area transportation planning, in: American Association of Geographers.
- Tilahun, N., Li, M., 2015. Walking access to transit stations: evaluating barriers with stated preference. *Transportation Research Record: Journal of the Transportation Research Board* , 16–23.
- Tilahun, N., Thakuriah, P., Keita, Y., 2013. Factors determining transit access by car owners: Implications for intermodal passenger transportation planning, in: Paper Presented at the 92nd Annual Meeting of the Transportation Research Board.
- Tilahun, N., Yin, S., Li, M., Keita, Y., 2015. Mapping Metropolitan Chicago Accessibility. Technical Report. The Travel Behavior & Urban Systems Research Group, Department of Urban Planning and Policy, University of Illinois at Chicago.
- Walton, D., Sunseri, S., 2010. Factors influencing the decision to drive or walk short distances to public transport facilities. *International journal of sustainable transportation* 4, 212–226.
- Wang, H., et al., 2012. Approximating the performance of a last mile transportation system. Ph.D. thesis. Massachusetts Institute of Technology.